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Development of an Integrated Solar Heat Pump Concept using Ice Slurry as a Latent Storage Material

Justin Tamasauskas[a,*], Michel Poirier[a], Radu Zmeureanu[b], Martin Kegel[a], Roberto Sunye[a]

[a]Natural Resources Canada/CanmetENERGY,1615 Lionel-Boulet Blvd, Varennes,Canada J3X 1S6
[b]Dept. Of Building, Civil, and Environmental Engineering, Concordia University,1455 De Maisonneuve Blvd. W, Montreal, Canada H3G 1M8

Abstract

This paper presents the design analysis of a solar heat pump using cool thermal storage. The integrated concept uses cool storage (sensible or ice-based) as a short-term (i.e. days, weeks) storage for solar energy in winter and cooling energy in the summer. Annual TRNSYS simulations are performed in four Canadian regions to identify the potential of ice storage and unglazed solar collectors. Results show that combining these two technologies can reduce mechanical system energy use by 17% - 28% compared to a cold-climate air-water heat pump. Unglazed collectors demonstrated potential in areas with milder winters.

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Keywords: solar; heat pumps; simulation; cold-climate; high performance housing; TRNSYS

1. Introduction

The Canadian residential sector accounts for 16% of national secondary energy use, with over 80% of this total directed towards space heating, cooling, and domestic hot water (DHW)[1]. Heat pumps can significantly reduce residential energy consumption by using renewable energy sources to efficiently meet building thermal demands. Currently, the majority of residential heat pumps in North America use air as the main source of thermal energy[2]. However, these units can lose a significant portion of heating capacity below 0°C, posing an issue in cold Canadian climates[3]. As such, there is a strong need to leverage other renewable energy sources to consistently meet building thermal demands during even the coldest winter days.

* Corresponding author. Tel.: +1-450-652-4822; fax: +1-450-652-5177
E-mail address: Justin.Tamasauskas@canada.ca

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Nomenclature

α	Solar absorptivity (-)
Δ	Temperature difference (°C)
ε	Solar emissivity (-)
ACH_{50}	Air changes per hour @ 50 Pa
Col	Solar collector
COP	Coefficient of performance (-)
DB	Dry bulb
DHW	Domestic hot water
Fluid	Fluid phase
HRV	Heat recovery ventilator
I	Initial
IT	Ice tank
M	Mass (kg)
N	Number of panels
Max	Maximum capacity of tank
SAHP	Solar assisted heat pump
T	Temperature (°C)
RF	Radiant floor
WB	Wet bulb
WT	Warm tank

Solar assisted heat pumps (SAHP) have shown promise in using low grade thermal energy to supplement and improve heat pump performance in cold climates[4]. Despite this strong energy savings potential, these systems face several challenges, including a lack of adequate thermal storage capacity and reduced solar gains in the winter months. In Canada, a growing demand for space cooling places an additional requirement on system functionality. Addressing these issues in a simple and effective manner is critical to the market acceptance of these systems.

Combining solar heat pumps with ice-based latent storage can significantly improve energy storage densities, while the use of a cold temperature working fluid in the solar collectors can increase thermal gains and extend collector utilization periods. Although several system configurations have been proposed for locations both in Europe and North America[5,6,7,8] there has been little analysis to quantify the impact of ice storage and identify the most effective configurations for different climates.

This paper presents a Canada-wide analysis on the role of ice storage and unglazed solar collectors for an innovative solar heat pump system. A simple cooling mode is also proposed in which a cool storage tank, charged during summer DHW operations, meets space cooling requirements for the building. Separate high performance housing models are developed for four Canadian regions and used to establish baseline energy consumption. Three distinct systems are then examined to identify the impact of ice storage and solar collector type on annual energy use. Finally, performance is presented on a system and component level to better assess each proposed design.

2. Development of High Performance Housing Models

Housing models are developed for four Canadian regions to identify the impact of climate on system energy performance. Table 1 summarizes key climate parameters for each region[9,10,11]. Heating and cooling degree days use a balance temperature of 18°C, while solar potential is shown for a surface tilted to the latitude of the location.

In Halifax, the Atlantic Ocean moderates temperatures, resulting in cloudier conditions with milder winters (in comparison to central Canada) and cool summers. Montreal represents a continental climate typical of central Canada, with cold winters and warm summers yielding significant space heating and cooling requirements. In Calgary, although winter temperatures can be quite cold, solar potential is high, making it an interesting candidate for solar-based systems. Finally a cool-marine climate prevails in Vancouver, with lower solar potential but a relatively high average annual air temperature near 10°C.